Unusual patterns of tooth wear among koalas *Phascolarctos cinereus* from St Bees Island, Queensland, require re-evaluation of criteria for aging koalas by tooth-wear class

Alistair Melzer[1#], William Ellis[1,2], Greg Gordon[4], Gail Tucker[1], Robyn Kindness[1] and Frank Carrick[3]

[1] Koala Research Centre of Central Queensland, CQ University, Bruce Highway, Rockhampton, Qld 4702
[2] San Diego Zoo Institute for Conservation Research, Zoological Society of San Diego, Escondido, CA, USA.
[3] Koala Study Program, Centre for Mined Land Rehabilitation, The University of Queensland, Qld 4072
[4] Department of Environment and Resource Management, Brisbane, Qld 4001
To whom correspondence should be addressed. a.melzer@cqu.edu.au

ABSTRACT

Tooth wear patterns among *P. cinereus* on St Bees Island in the humid Central Queensland Coast bio geographic region differ significantly from those observed in the sub-humid Brigalow Belt bio geographic region. Within the Brigalow Belt region, tooth-wear patterns among *P. cinereus* at Biloela, Springsure and Oakey are similar. The published method for the estimation of age based on tooth-wear from *P. cinereus* populations at Springsure and Oakey is applicable to the Biloela population but is not applicable to the St Bees Island population. It is concluded that, in Queensland at least, the tooth wear – age class classification should be verified with local data when applied in environments different from those of the Brigalow Belt. Further, the appropriateness of using a single tooth-wear classificatory scheme to establish the age of *P. cinereus* for transfer overseas is questioned.

Key words: koala, *Phascolarctos cinereus,* tooth wear, age class, export koalas

Introduction

Koalas *Phascolarctos cinereus* have their full complement of teeth by the time they are 18 months old (Blanshard 1990). Wear continues for the life of the individual and some old animals may have extremely worn incisors and molars. Enamel on all occlusal surfaces wears, eventually exposing the underlying dentine. The premolar and molar row appear to wear progressively from the premolar along the molar row towards the rear fourth molar. Martin (1981), Gordon (1981) and McLean (2003) used this characteristic to assign wear patterns to age classes among *P. cinereus* in Queensland (Gordon 1991) and Victoria (Martin 1981, McLean 2003). These authors found little difference in tooth-wear among the populations they studied but raised the possibility that the pattern could vary with the characteristics of the fodder consumed, since the abrasiveness of the fodder, as well as the occlusal action, can influence tooth wear (Lanyon and Sanson 1986). Despite this, the published tooth-wear classificatory scales devised by Martin (1981) and Gordon (1991) are widely applied in field studies (*e.g.* White and Kunst 1990, Melzer 1995, Logan and Sanson 2002, Dique *et al.* 2003, Kavanagh *et al.* 2007) while the Australian Government requires the use of tooth-wear to estimate and certify the age of export *P. cinereus* proposed for export where age cannot be determined by date of birth (DEH 2009).

We have been collecting skeletal material from animals that have died from natural causes in wild, free ranging Queensland populations of *P. cinereus* as part of our studies on the estimation of age (Gordon 1991), demography (Penn *et al.* 2000), morphological difference among populations (Melzer 1995) and some disease syndromes (Melzer unpublished data), since the early 1970's. Most recently (since 2000) we have been investigating *P. cinereus* and associated habitat in the humid eucalypt forests on St Bees Island off the central Queensland coast near Mackay. Very early in this study it became apparent that the observed patterns of tooth-wear were not consistent with the overall appearance of animals being handled.

Our extensive archive of skulls from inland southern and central Queensland as well as from St Bees Island has provided an opportunity for quantitative examination of this inconsistency and test for differences in tooth-wear among populations.

Furthermore, since we understand the diet of St Bees Island *P. cinereus* (99% *E. tereticornis* - Tucker *et al.* 2007) and at least one other site (Springsure: *Eucalyptus tereticornis* 49.9%, *E. crebra* 23.6%, and *E. melanophloia* 12.8% - Melzer1995), we were able to consider whether there was a difference in fodder fibre and inorganic matter content between two sites that may contribute to any differences tooth-wear patterns.

So our objectives were, firstly to investigate differences in tooth-wear patterns between St Bees Island *P. cinereus* and some other Queensland *P. cinereus* populations; and secondly to see whether differences in fodder characteristics may reflect any differences between the Springsure and St Bees Island populations.

Methods

Skulls were collected from skeletal material encountered incidentally at four sites – Oakey (27° 26’ S, 151° 43’ E), Springsure (24° 07’ S, 148° 05’ E), Biloela (24° 24’ S, 150° 31’ E) and St Bees Island (20° 56’ S, 149° 26’ E). Most material was collected from fully decomposed animals and, consequently, the sex of the individuals was not usually apparent. Because adult male koalas have larger heads than adult females and there was advanced tooth wear within the mainland populations, it is possible to ascribe a gender to the skulls of older animals. However, the general absence of advanced tooth-wear among skulls from St Bees Island precluded the separation of potentially young males from females on the basis of skull length (see McLean 2003). So the samples were combined within sites.

Tooth wear

The skulls from Oakey were used by Gordon (1991) in the development of his tooth-wear classification. Here we applied this scheme to tooth-wear from the upper right pre-molar and right molars of skulls from all sites and ascribed a tooth-wear class from 1 to 10 and estimated age up to 9 years for each sample.

Condylo-incisive length

As *P. cinereus* grows, condylo-incisive length increases in a process that slows as the animal matures (Blanshard 1990, Gordon 1991, Melzer 1995, McLean 2003). So any relationship between age and condylo-incisive length is lost from about 2 years of age (Gordon 1991, McLean 2003). We used condylo-incisive length to compare the relative maturity of the skulls examined among the populations. This is important as about 73% of St Bees Island skulls exhibited tooth-wear usually ascribed to younger animals (less than three years old).

Reference material

All skeletal material used was vouchered and retained for future reference. Skulls from Springsure, Biloela and St Bees Island are held under permit at Central Queensland University in Rockhampton. Skulls from Oakey are lodged with the Queensland Museum.

Analyses of skulls and tooth-wear

The data for tooth-wear were summarised as relative frequency (%). Data for condylo-incisive length were summarised as mean and standard deviation. The relationship between condylo-incisive length and tooth-wear within populations was expressed as a scattergram. Difference in tooth-wear class frequency and in condylo-incisive length among sites was tested by analysis of variance among, and a *post hoc* Tukey comparison between, sites.

Foliar analyses

Eucalyptus tereticornis foliage was collected from Homestead Bay on St Bees Island (20° 55’ 32.23S, 149° 25’ 56.64” E). *Eucalyptus tereticornis* and *E. crebra* foliage was collected from Norwood Creek at Springsure (24° 06’ 46.58 S, 148° 01’ 51.46” E). At each location new fully expanded leaves and petioles from 10 trees of each species were collected, washed to remove surface contamination and dried to constant weight. While koalas consume foliage of varying age, the collection of new, fully expanded foliage from each site was undertaken to reduce some variability between sites and among trees. Foliar analyses were undertaken by M. Neilsen, University of the Sunshine Coast. Sub samples were ashed to determine % inorganic content. Lignin and fibre analyses followed Van Soest (1963) using an Ankom 220 Fibre Digestion Unit. The non-parametric Kolmogorov-Smirnov test was applied to test difference between samples.

Monitoring koala longevity

St Bees Island koalas have been fitted with radio transmitting collars and ear tags since 2000 and subsequently monitored quarterly up to October 2006. This was part of a long term multidisciplinary study of *P. cinereus* on St Bees Island. The island population of an estimated 200 *P. cinereus* is descended from less than 20 individuals introduced from the adjacent mainland in the late 1930s (Berck 1995). Our interest in this population arose from anecdotal accounts of the apparently stable island *P. cinereus* populations in Queensland (Melzer *et al.* 2000) – in stark contrast to southern island populations with their reported tendency to grow exponentially and outstrip habitat resources (*e.g.* Kangaroo Island, Duka and Masters 2005). The documented history of introduction to St Bees Island, its secure tenure as a National Park, the relatively low vegetation and easy access to wild koalas make St Bees Island an excellent field research site.

Table1. Relative frequency (%) of tooth-wear class and age (mean years) (Gordon 1991) at Springsure, Oakey, Biloela and St Bees Island.

TWC	1	2	3	4	5	6	7	8	9	10
Mean Age	1.2	2.0	2.7	4.3	5.5	7.3	9.0			
St Bees N=60	28.33	33.33	11.67	8.33	10.0	3.33			1.67	3.33
Springsure N=50	6.0	16.0	8.0	8.0	26.0	30.0	6.0			
Biloela N=34	5.88	17.65	17.65	8.82	29.41	5.88	14.71			
Oakey N=50		14.0	16.0	4.0	10.0	34.0	20.0	2.0		

Results

Tooth-wear

Fifty skulls were collected from both Springsure and Oakey. Sixty skulls were collected from St Bees Island. Thirty-four skulls were collected from Biloela. The relative occurrence of tooth-wear classes at the mainland sites was similar (Table 1). A bimodal distribution is apparent with peaks around classes 2-3 and 5-7. The distribution from St Bees Island is different. One peak, around classes 1 and 2, accounts for about 62% of observations (Table 1). There was a significant difference in tooth-wear class among the sites ($F_{3,190}=13.443$ $p=0.0000$). St Bees Island differed significantly from the Biloela ($p=0.0000$), Springsure ($p=0.006$) and Oakey ($p=0.0000$) populations.

Condylo-incisive length

The range in condylo-incisive length at each of the sites is summarised in Table 2 and illustrated in relation to tooth-wear class in Figure 1. There was no difference among the four populations ($F_{3,187}=0.30192$, $p=0.824$).

Foliar lignin and inorganic matter

The percent inorganic matter and percent lignin data from *E. tereticornis* from St Bees Island and *E. tereticornis* and *E. crebra* from Springsure are summarised in Table 3.

Inorganic matter

There was significantly less inorganic matter in *E. tereticornis* than in *E. crebra* ($p= 0.005$) at Springsure but no significant difference in *E. tereticornis* between Springsure and St Bees Island ($p > 0.05$), or between St Bees *E. tereticornis* and Springsure *E. crebra* ($p > 0.1$).

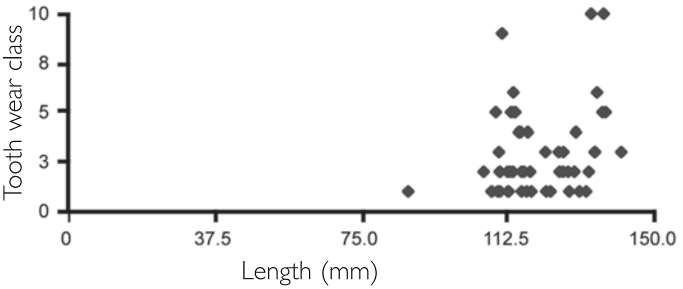
Lignin

There was significantly more lignin in St Bees Island *E. tereticornis* than in Springsure *E. crebra* ($p= 0.025$). There was no difference between lignin in St Bees Island *E. tereticornis* and Springsure *E. tereticornis* ($p > 0.1$). Nor were there differences between the percentage of lignin in *E. tereticornis* and *E. crebra* from Springsure ($p > 0.1$).

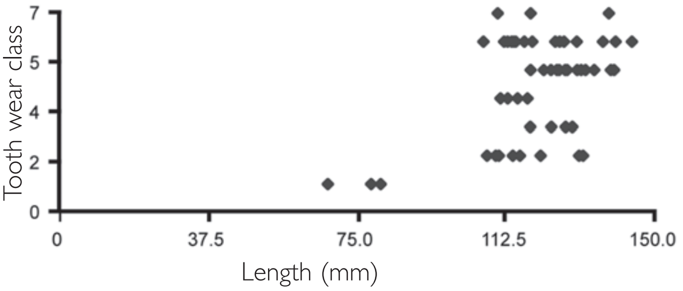
Observed longevity

As of October 2006 continuous data have been collected on 11 St Bees Island individuals over a period from 3.3 to 6.7 years. One individual has been monitored for 5.6 years since it was a dependent juvenile (weight =1.0kg). Two were collared as just-weaned sub adults (weight = 2 – 2.6 kg) and have been monitored for 3.3 and 5.6 years respectively. Eight were collared as adults (female weight range 5.6-7.5kg, n=5; male weight range 6.9-8.9kg, n=3) and have been monitored for between 3.75 and 6.67 years. Monitoring of these animals is continuing and documented life-spans will increase.

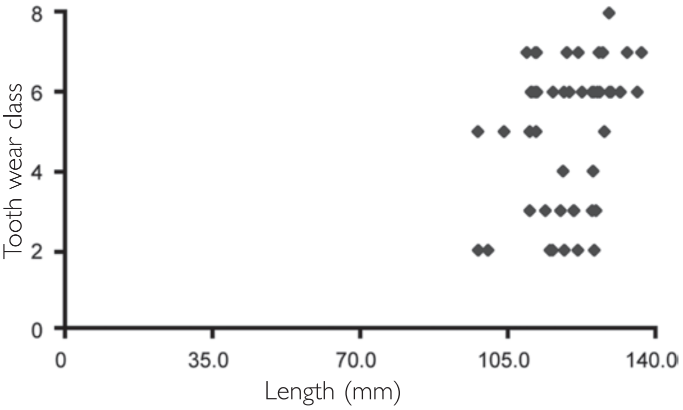
a. St Bees Island



b. Springsure



c. Oakey



d. Biloela

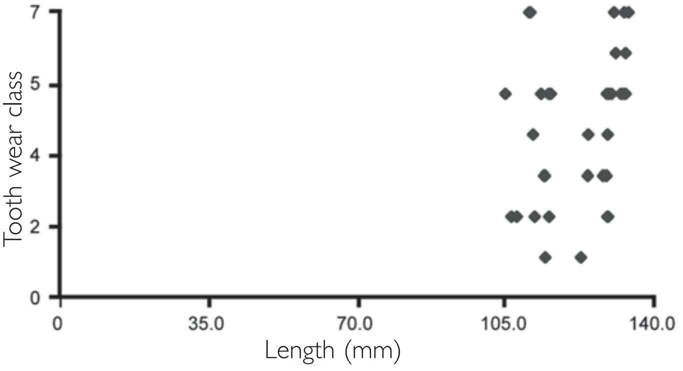


Figure 1. Relationship between tooth-wear class and condylo-incisive length (a) St Bees Island n=60, (b) Springsure n=60, (c) Oakey n=50, (d) Biloela n=34.

Table 2. Condylo-incisive length of skulls at Springsure, Oakey, Biloela and St Bees Island. (*Data not available on skull 60)

Locality	Mean length (mm)	Standard Deviation	Sample Size
Springsure	120.4	14.9	50
Oakey	121.1	9.1	49
Biloela	122.0	9.1	34
St Bees Isl.	117.7	7.1	59*

Table 3. Inorganic matter and lignin content (% dry weight) of *Eucalyptus tereticornis* and *E. crebra* from Springsure and St Bees Island.

(mean (standard deviation) sample number)

Locality	Species	% Inorganic Matter	% Lignin
St Bees Isl.	*E. tereticornis*	5.49 (0.98) 10	15.38 (3.37) 10
Springsure	*E. tereticornis*	4.68 (0.78) 10	12.85 (2.53) 10
Springsure	*E. crebra*	6.33 (1.09) 10	10.36 (1.77) 10

Discussion

Tooth-wear and age

Self-evidently, tooth-wear stops at death and so provides a useful tool to estimate lifespan in wild, free ranging populations (*e.g.* Melzer 1995, Penn *et al.* 2000). If the tooth-wear classification of these skulls accurately reflects the age at death then our results suggest two peaks in mortality at Springsure, Oakey and Biloela – one around 2-3 years and the second around 5-9 years of age. The data from St Bees Island suggest most mortality occurs around 1-3 years (Table 1). However, the data on condylo-incisive length suggest that the St Bees population are of similar age to the Springsure, Oakey and Biloela populations and that a similar tooth-wear pattern would be expected. Conversely the St Bees Island *P. cinereus* may have grown rapidly and the deaths at tooth wear classes 1 and 2 (Table 1) are indeed occurring after 1 – 3 years of age. However, the long term monitoring of the individuals on St Bees Island does not support this and suggests that life span in these animals is at least 3.75 to 6.67 years and that the rate of tooth-wear is different to that of the mainland populations assessed.

Fodder quality and bioregional differences

There was little difference between the foliage from St Bees Island and from Springsure. The percentage inorganic matter tended to be higher in Springsure *E. crebra* than in St Bees Island *E. tereticornis*. Conversely, lignin tended to be greater on St Bees Island than at Springsure – although not significantly so. Larger sample sizes are likely to reduce the variance and better define the differences. Despite that, the tendencies may point to a rationale for differential tooth-wear rates. Lithgow (1980), cited in McLean 2003, suggested that *P. cinereus* may experience higher rates of tooth-wear when fodder with a higher silica content is a significant component of the diet. Higher lignin content of *E. tereticornis* points to a greater mastication effort per unit foliage than for *E. crebra* and tending to be more so on St Bees Island. This could imply greater wear from tooth-to-tooth contact masticating *E. tereticornis* than masticating *E. crebra* (Walker *et al.* 1978, Kaiser *et al.* 2009). So the results of this limited study are equivocal and more extensive trials are required. However, abrasion from dust or grit contamination of fodder may also be important, particularly in drier regions (*e.g.* Haynes 1984, Kaiser *et al.* 2009) and future studies will collect additional samples to investigate this possibility (our efforts to reduce confounding effects by washing leaf samples precluded this in the present study).

The data suggest that similar rates of tooth-wear occur among the Springsure, Oakey and Biloela populations and that a much reduced tooth-wear rate occurs among many St Bees Island *P. cinereus*. This confirms previous observations on Springsure and Oakey *P. cinereus* populations, which exhibited similar tooth-wear characteristics (Gordon 1991). Our observations indicate that tooth-wear among *P. cinereus* from Biloela is similar to that found at Springsure and Oakey.

All three of these localities lie within the Brigalow Belt bio geographic region (Sattler and Williams 1999). A bio geographic region encompasses lands related by geography, climate, floristic association and faunal assemblages. The Brigalow Belt bio geographic region is characterised by the presence of Brigalow (*Acacia harpophylla*), 500 – 750 mm rainfall and dry open forests, woodlands, grasslands and associated "dry" communities. St Bees Island lies in the Central Queensland Coast bio geographic region. This is a relatively wet region receiving up to 2000 mm annual rainfall and supporting relatively moist woodlands and forests as well as "wet" rainforests. It is tempting to suggest that the tooth-wear pattern reflects less abrasive characteristics of foliage growing in more mesic environments such as on St Bees Island, or that the island's foliage may have higher nutritional loads and/or water content and thus a smaller quantity of leaf is required to satisfy metabolic requirements, or the possibility (yet to be tested) that there is a much reduced load of abrasive dust on St Bees Island foliage.

Conclusions

Whatever the cause, there are consistent tooth-wear patterns among three widely separated sites within the sub humid Brigalow Belt Bio region and these are different from the one site within the humid Central Queensland Coast Bio region. We conclude that age estimation from tooth-wear in Queensland *P. cinereus* populations experiencing very different environments from the Brigalow Belt bio geographic region will require reclassification of wear patterns derived from local known age *P. cinereus*. This result suggests that the policy of applying a single tooth-wear classificatory scheme to the regulation and statutory management of *P. cinereus* (DEH 2009) requires reconsideration, especially as most exported individuals are derived from populations of northern koalas, predominantly from Queensland (F. Carrick pers. com.2010, UQ).

Finally, the tooth-wear patterns on St Bees Island hint at an interesting demographic profile for this population. There is a small cohort with high tooth wear suggesting relatively great age. Work is continuing to develop an effective means to determine the age of these individuals so as to understand the age structure of this island population of *P. cinereus*.

Acknowledgements

Earthwatch International and the associated volunteer teams as well as the Central Queensland Koala Volunteers supported the St Bees Island research. Australians for Animals, Callide Coal Mine and North Rockhampton State High School supported the Biloela research. The Australian Koala Foundation and the BHP Foundation supported the Springsure research.

References

Berck, L 1995. *St Bees Island: its history, lifestyle and tales*. Boolarong Press, Mackay, Queensland.

Blanshard, W. H. 1990. Growth and development of the koala from birth to weaning. Pp 193 – 202 in *Biology of the koala*, edited by A.K. Lee, K. A. Handasyde and G.D. Sanson.) Surrey Beatty and Sons, Chipping Norton, NSW, Australia.

DEH 2009. *Conditions for the overseas transfer of koalas*. Australian Government, Department of Environment and Heritage, Effective from April 2009. (www.environment.gov.au/biodiversity/trade-use/publications/export-conditions).

Dique, D.S., Thompson, J., Preece, H.J., Penfold, G.C., deVilliers, D.L. and Leslie, R.S. 2003. Koala mortality on roads in south-east Queensland: the koala speed-zone trial. *Wildlife Research* **30**, 419-426.

Duka, T. and Masters, P. 2005. Confronting a tough issue: Fertility control and translocation for over-abundant Koalas on Kangaroo Island, South Australia *Ecological Management and Restoration* **6 (3),** 172-181.

Gordon, G. 1991. Estimation of the age of the koala, *Phascolarctos cinereus* (Marsupialia: Phascolarctidae) from tooth wear and growth. *Australian Mammalogy* **14**, 5-12.

Haynes, G. 1984. Tooth wear rate in northern bison. *Journal of Mammalogy* **65 (3)**, 487-491.

Kaiser, T.M., Brasch, J., Castell, J.C., Schulz, E. and Clauss, M. 2009. Tooth wear in captive wild ruminant species differs from that of free-ranging conspecifics. *Mammalian Biology* **74**, 425-437.

Kavanagh, R. P., Stanton, M.A. and Brassil, T.E. 2007. Koalas continue to occupy their previous home-ranges after selective logging in *Callitris-Eucalyptus* forest. *Wildlife Research* **34**, 94-107.

Lanyon, J.M. and Sanson, G.D. 1986. Koala (*Phascolarctos cinereus*) dentition and nutrition: II. Implications of tooth wear in nutrition. *Journal of Zoology* **209**, 169-182.

Lithgow, K.A. 1980. *Aspects of the Feeding Ecology of the Koala,* Phascolarctos cinereus, *in Victoria.* Honours Thesis. Monash University: Melbourne.

Logan, M. and Sanson, G.D. 2002. The effects of tooth-wear on the activity patterns of free-ranging koalas (*Phascolarctos cinereus* Goldfuss). *Australian Journal of Zoology* **50**, 281-292.

Martin, R. W. 1981. Age-specific fertility in three populations of the koala, *Phascolarctos cinereus* Goldfuss, in Victoria. *Australian Wildlife Research* **8,** 275-283.

McLean, N. 2003. *Ecology and management of overabundant koala* (Phascolarctos cinereus) *populations*. Thesis, University of Melbourne.

Melzer, A. 1995. *Aspects of the ecology of the koala* Phascolarctos cinereus *(Goldfus, 1817), in the sub-humid woodlands of central Queensland*. PhD thesis, University of Queensland.

Melzer A., Carrick F., Menkhorst P., Lunney D. and St John B. 2000. Overview, critical assessment and conservation implications of koala distribution and abundance. *Conservation Biology* **14 (3),** 619-628.

Penn, A.M., Sherwin, W.B., Gordon, G., Lunney, D., Melzer, A., and Lacy, R.C. 2000. Demographic forecasting in Koala Conservation. *Conservation Biology* **14 (3)**, 629-638.

Sattler, P. S. and Williams, R. D. (eds) 1999. *The conservation status of Queensland's bioregional ecosystems*. (Environmental Protection Agency: Brisbane).

Tucker, G., Melzer, A. and Ellis, W. 2007. The development of habitat selection by subadult koalas. *Australian Journal of Zoology*. **55,** 1-5.

Van Soest, P.J. 1963. Use of detergents in the analysis of fibrous feeds. A rapid method for the determination of fiber and lignin. *Journal of the Association of Official Analytical Chemists.* **46**, 829-835.

Walker, A. Hoek, H.N. and Perez, L. 1978. Microwear of mammalian teeth as an indicator of diet. *Science* **201 (8)**, 908-910.

White, N.A. and Kunst, N.D. 1990. Aspects of the ecology of the koala in southeastern Queensland. Pp 109-116 in *Biology of the koala*, edited by A.K. Lee, K. A. Handasyde and G.D. Sanson.) Surrey Beatty and Sons, Chipping Norton, NSW, Australia.